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Designated high contracting parties to regional patent conventions: FR GB IT NL SE

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[Title in German of the object of the invention:]

Filterbank zum Frequenzmultiplexen bzw. Frequenz[de]multiplexen von Kanalsignalen

FILTER BANK FOR THE FREQUENCY MULTIPLEXING, RESPECTIVELY FREQUENCY DEMULTIPLEXING OF CHANNEL SIGNALS

The invention pertains to a filter bank, pursuant to the preamble of patent claims 1 or 2.

Filter banks are known, as a result of the monograph by Del Rei and Emiliani, entitled "An Analytical Signal Approach for Multiplexers: Theory and Design", in IEEE Transactions on Communications, vol. Com-30, # 7, July 1982, pp 1623 and subsequent.

Filter banks are essentially used in so-called transmultiplexers for the multiplexing or demultiplexing of FDM* individual channels. [*Translator's note: FDM = Frequency Division Multiplexing] Transmulltiplexers are used for the conversion from FDM to TDM* [*Translator's note: TDM = Time Division Multiplexing], or vice versa, and are finding application in the satellite engineering or in the telephone network. It is exactly in the satellite engineering where the supreme commandment is to reduce as much as possible the loss of the payload.

In the principal patent application, there are conceived filter banks, which provide for channel branches in the individual filter cascades.

In the first patent application of addition, there were presented filter banks, in which - after defined, or in front of defined analogous cascade stages, a multiplier is inserted in all channel branches, as a result of which multiplier the coefficients of the subsequent filter are identical and real-valued ones in all channel branches with regard to a cascade stage.

The objective to specify a filter bank of the kind, mentioned at the outset, for which filter bank the required processing power, and, therewith, the input is further reduced, forms the basis of the proposed invention.

The set objective is achieved with the help of the characteristic features of patent claim 1, resp. 2.

The filter bank in accordance with the invention has the advantage of a reduced circuit input or degree of sophistication. Advantageous embodiments of the invention ensue from the subclaims.

The description of the invention follows by means of the figures.

Figs. 1a and 1 b show the cascaded filter bank in accordance with the first patent application of addition, which cascaded filter bank is having a multiplier after the first, respectively after the second cascade stage.

Figs. 2a and 2b diagrammatically represent the combination of the subsequent complex multiplier with the filter of the preceding cascade stage.

Fig. 3a diagrammatically represents in detail a block diagram for the block in Fig. 2a, depicted with dotted lines in Fig. 2a, and Fig. 3b diagrammatically represents a combination - in accordance with the invention - also in the form of a detailed block diagram.

Finally, Fig. 4 shows the arrangement for a combination - in accordance with the invention - depicted in Fig. 2b in the form of a block diagram, whereby the two blocks or units correspond to the detailed block diagram depicted in Fig. 3b. As a matter of principle, not only is the block diagram, drawn in this case, valid for the combination of the complex multipliers with the preceding two stages but also for relevant combinations in the

subsequent stages.

An attempt is being made as follows to represent how the processing power is reduced as a result of the combination in accordance with the invention.

Pursuant to the prior art in accordance with the principal patent application, respectively first patent application of addition, corresponding to Fig. 3a, the coefficients of the half bandpass filter, depicted in Fig. 3a, are calculated as prototype filter, having real coefficients and a zero phase from φ_0 to (in Fig. 3a: $\varphi_0 = 0$):

$$h_l(\nu) = h(\nu) \cdot e^{j(2\pi f_l / f_A + \varphi_0)} = h_r(\nu) + j\, h_i(\nu)$$
$$= h(\nu) \quad \cos\left(2\pi\nu \frac{f_l}{f_A} + \varphi_0\right) + j \sin\left(2\pi\nu \frac{f_l}{f_A} + \varphi_0\right),$$

whereby f_l is the center frequency of the channel in question at the input of the first filter of the cascade, and f_A is the corresponding sampling frequency. In that case, the time-variable coefficients, parameter k, of the solution in accordance with Fig. 3b are provided by:

$$\underset{\sim}{h}_{l}(\nu,k) = \underset{\sim}{h}_{l}(\nu)\, e^{-j\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)}$$

$$= h_{rl}(\nu,k) + j\, h_{il}(\nu,k)$$

$$= \underset{\sim}{h}_{l}(\nu)\left[\cos\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right) - j \sin\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)\right]$$

thus

$$\underset{\sim}{h}_{l}(\nu,k) = h(\nu)\cos\left(2\pi\nu\frac{f_l}{f_A} + \varphi_0\right)\cos\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)$$

$$+ h(\nu)\sin\left(2\pi\nu\frac{f_l}{f_A} + \varphi_0\right)\cdot\sin\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)$$

$$+ j\left\{h(\nu)\sin\left(2\pi\nu\frac{f_l}{f_A} + \varphi_0\right)\cos\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)\right.$$

$$\left. - h(\nu)\cos\left(2\pi\nu\frac{f_l}{f_A} + \varphi_0\right)\sin\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)\right\}$$

$$= h_r(\nu)\cos\left(2\pi k \frac{f_l^I}{f_A^I} + \varphi_0\right) + h_i(\nu)\sin\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)$$

$$+ j\left\{h_i(\nu)\cos\left(2\pi k \frac{f_l^I}{f_A^I} + \varphi_0\right) - h_r(\nu)\sin\left(2\pi k \frac{f_l^I}{f_A^I} + \phi_0\right)\right\}.$$

With the help of the addition theorem of trigonometry, the following result is obtained:

$$\underset{-}{h}_{l}(\nu,k) = h(\nu)\cos\left[2\pi\left(\nu\frac{f_l}{f_A} - k\frac{f_l^I}{f_A^I}\right) + \varphi_0 - \phi_0\right]$$

$$+ jh(\nu)\sin\left[2\pi\left(\nu\frac{f_l}{f_A} - k\frac{f_l^I}{f_A^I}\right) + \varphi_0 - \phi_0\right]$$

$$= h(\nu)\, e^{j\left(2\pi\nu\frac{f_l}{f_A} + \varphi_0\right)} \cdot e^{-j\left(2\pi k\frac{f_l^I}{f_A^I} + \phi_0\right)}$$

$$= h(\nu)\, e^{j\left(2\pi\left[\nu\frac{f_l}{f_A} - k\frac{f_l^I}{f_A^I}\right] + \varphi_0 - \phi_0\right)}$$

$$= h_r(\nu,k) + j\, h_i(\nu,k)\,.$$

f_l^I is the center frequency of the channel in question after the sampling frequency has been halved into f_A^I = $f_A/2$ in connection with the filtering in the first filter of the cascade. If f $f_l^I < f_A^I$, then $f_l^I = f_1$. The first filter stage operates with real input signal and complex output signal.

For the equation (1) and the preceding equations, the parameters v and k are yet to be elucidated in greater detail. v denotes the position of the coefficient in the filter. k denotes

the time dependency or correlation of the coefficients. Due to this time dependency, the symmetry of the coefficients is not anymore present as in the case of the filter bank in accordance with the principal patent application and first patent application of addition. The coefficients change sinusoidally, i.e. periodically. Thus, only a limited number of different coefficient values are to be made available and stored. The multiplication and addition rates for a six-stage filter cascade are calculated.

In the first case - in doing so - the question under consideration pertains to an embodiment, having discrete complex multipliers after the first cascade stage in accordance with the patent application of addition, corresponding to the arrangement depicted in Fig. 1a. In that case, a multiplication rate of $M_{II} = 364 \cdot f_A^{VI}$ and an addition rate of $A_{II} = 316 \cdot f_A^{VI}$ are required. If in the case of the aforementioned arrangement in accordance with the submitted second patent application of addition, the complex multiplier is combined with the filter of the preceding cascade ~~stage,~~ this first preceding filter No.1 is thus time-variant~~,~~ and the subsequent filters No. 2 thru 6 are time-invariant~~,~~ having real coefficients, and the multiplication rate is computed as follows.

$$M_{III} = (n_I + 3) f_A^I + 2 \sum_{q=II}^{VI} \frac{n_q + 5}{4} f_A^q$$

$$= \left[6 \cdot 32 + 4 (16 + 8) + 6 (4 + 2) + 8 \right] f_A^{VI}$$

$M_{III} = 332 f_A^{VI} < M_{II}$

Addition rate:

$$A_{III} = (n_I + 1) f_A^I + 2 \sum_{q=II}^{VI} \frac{n_q + 1}{2} f_A^q$$

$$= \left[4 \cdot 32 + 4 (16 + 8) + 8 (4 + 2) + 12 \right] f_A^{VI}$$

$A_{III} = 284 f_A^{VI} < A_{II}$

The features of the filter arrangement of in accordance with the second patent application of addition are listed as follows. As in the case of the filter banks in accordance with the first patent of addition, all filters of a cascade after the time-variant filter, into which the multiplier is integrated, are identical for all L-channels, and have real coefficients. Because of the fact that the coefficient symmetry does not exist in the time-variant filter, the computation input in accordance with the submitted invention is less only in the case of comparable and corresponding arrangements in accordance with the first patent application oaf addition, utilizing the symmetry, when stage 1 is

time-variant and the filter order $f_1 = 3$ (see example).
If for practical reasons, the coefficients' symmetry could not be utilized in the case of the arrangements of the first patent application of addition, then - in that case - the computation input for the arrangements in accordance with the invention is reduced - pursuant to the submitted second patent of addition - in all cases, regardless of the fact where the time-invariant filter is settled, i.e. the time-variant filter can be arranged in all cascade stages, from the first to the last stage, including the latter.

Self-evidently, the principle in accordance with the invention, pursuant to which a complex multiplexer is combined with the filter of an adjacent cascade, can also be applied to FDM multiplexers, which originate from the demultiplexer, e.g., depicted in Figures 2a or 2b, in a simple way as a result of inverse function, i.e., by means of a mode of operation in reverse direction.

Claims

1. Filter bank for frequency demultiplexing of L channel signals, for L > 0 and L a positive integer [natural number], consisting of L transversal filters (non-recursive filters, filters having long duration of the *f*inite *i*mpulse *r*esponse(FIR), having complex valued coefficients, for real-valued input signals, and having complex-valued output signals, with sampling rate, reduced by the

factor M at the output, whereby at least one of the L filters is materialized by means of a cascading of at least 2 filters, having relevant complex-valued coefficients, whereby in the case of each filter ($F_1, \ldots F_q, \ldots F_Q$) inside this cascade, the sampling rate is reduced by the factor $M_q > 1$, with

$$\prod_{q=1}^{Q} M_q = M,$$

whereby the input filter (F_1) of the cascade receives a real-valued input signal, and emits a complex-valued output signal, and whereby the other filters of the cascade receive a complex-valued input signal and emit a complex-valued output signal, whereby in the individual filter cascades between two analogously numbered cascade stages, following one after another, there is inserted a complex multiplier, by means of which the complex-valued output signal of the filter of the preceding cascade stage (q-1), respectively the input signal, is multiplied by the complex sequence of such a sampled, complex carrier wave, so that the filters of the subsequent cascade stages (q) consist of two separate, identical low-pass filters, having real coefficients, respectively, in accordance with patent application P 38 36 081.0, BK 87/40, characterized in that the multiplier is combined with the filter of the preceding cascade stage.

2. Filter bank for frequency multiplexing of L channel signals, for L > 0 and L a positive integer, consisting of L transversal filters (non-recursive filters, filters having long duration of the

finite impulse response(FIR), having complex valued coefficients, for complex-valued input signals and real-valued output signals, having sampling rates, elevated by the factor M at the output, whereby at least one of the L filters is materialized by means of a cascading of at least 2 filters, having complex-valued coefficients, respectively, whereby in the case of the filters ($F_1, \ldots F_q, \ldots F_Q$) inside this cascade, the sampling rate is increased by the factor $M_q > 1$ with

$$\prod_{q=1}^{Q} M_q = M,$$

whereby the Q-1 first filters ($F_1, \ldots F_s, \ldots F_{Q-1}$) of the cascade receive a complex-valued input signal, and emit a complex-valued output signal, respectively, and whereby the output filters of the cascade receive a complex-valued input signal, and emit a real-valued output signal, respectively, whereby a complex multiplier is inserted in the individual filter cascades in front of the same cascade stage, respectively, by means of which complex multiplier the complex-valued output signal of the filter of the preceding cascade stage, resp. the input signal, is multiplied by complex sequence of a sampled, complex carrier wave of this kind, so that the filters of the preceding cascade stages consist of two separate, identical low-pass filters, having real coefficients, in accordance with patent application P 38 36 081.0, BK 87/40, characterized in that the multiplier is combined with the filter of the subsequent cascade stage.

3. Filter bank as claimed in claim 1 or 2, characterized in that

the factor M is resolved into two factors, having a power of two, 2^l, as first factor, and a second factor, which is equal to $M/2^l$, with l being a positive integer.

4. Filter bank as claimed in claim 3, characterized in that the power of two, 2^l, is materialized by means of a cascade of **i** filters, having $M_q = 2$, respectively.

5. Filter bank as claimed in claim 4, characterized in that the filters of this cascade are materialized as complex half-bandpass filters.

6. Filter bank as claimed in one of the preceding claims, characterized in that the complex carrier wave of the function $e^{-j2\pi k f_l^q / f_A^q}$ suffices, whereby k denotes the number of the scan sample (discrete time-variable), f_l^q denotes the channel-band center frequency of the channel l in the q^{th} cascade stage.

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2 drwgs.

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January 6, 2005

FIG. 1a

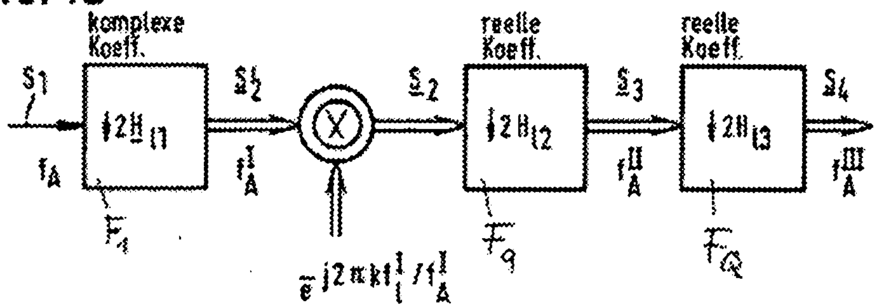

FIG. 1b

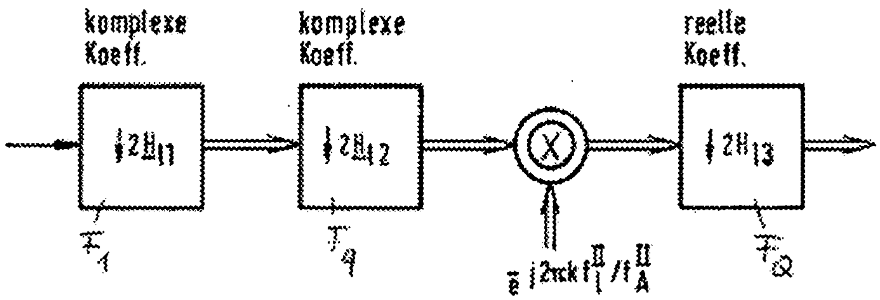

FIG. 2a

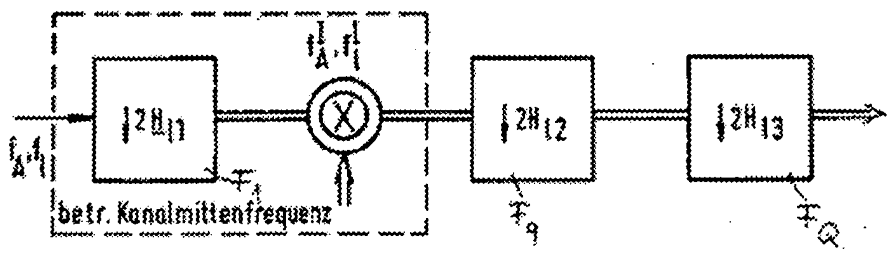

FIG. 2b

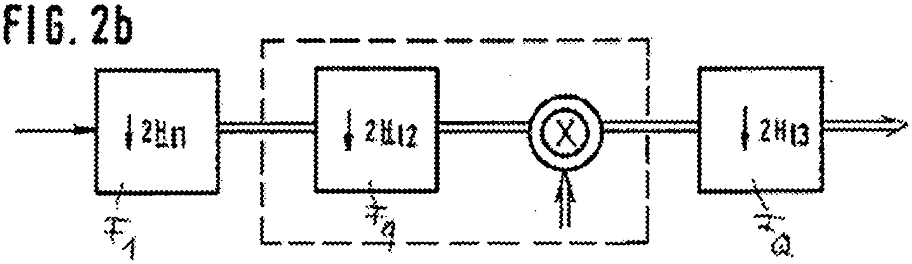

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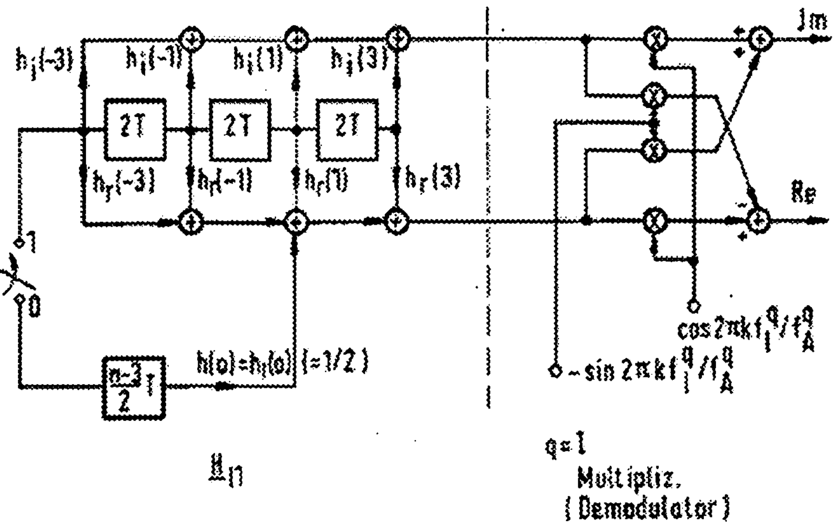
FIG.3a



$f_A = \frac{1}{T} = f_A^0$

FIG.3b

(n+3) Multipl.
(n+1) Add.

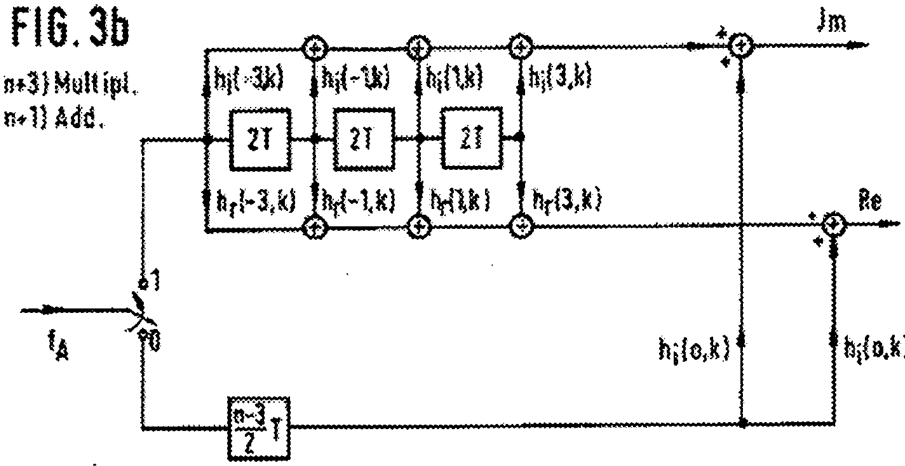
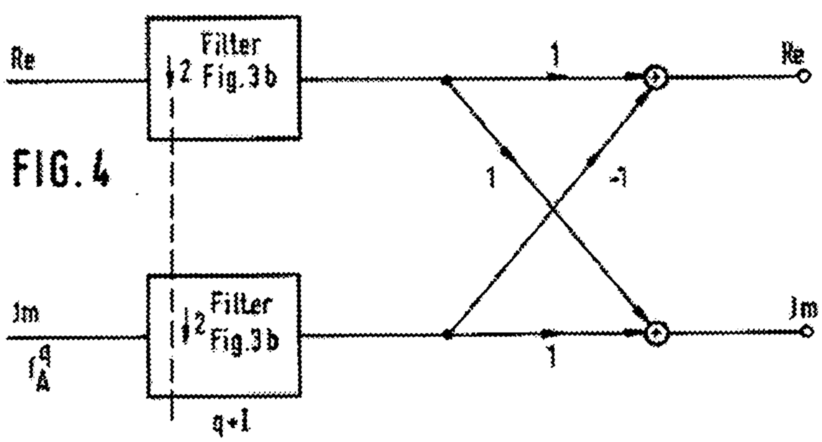


FIG.4



BK 87/41

CHG DATE=19990617 STATUS=O> Filter bank for frequency-division multiplexing or frequency- division demultiplexing of L-channel signals with transversal filters at reduced or increased sampling rate, the L-filters being implemented by means of a cascade and a complex multiplier being inserted between the individual filter cascades, characterised in that the multiplier is combined with the filter of the preceding and following cascade stage. Such filter banks are mainly used in transmultiplexers for conversion from FDM into TDM and conversely, mainly in satellite engineering. It is the aim of the invention to reduce the required computing power. By combining the complex multiplier with the adjacent **filter, a time-variant filter** is produced but the **filters** of the other cascade stages are **time-invariant** as before and contain real **coefficients**. Seen overall, a lower computing effort is required, the number of coefficients to be stored increasing only insignificantly (Figure 2a and 2b). <IMAGE>